Vol. VIII. JANUARY, 1892. No. 9.

American Meteorological Journal.

A Monthly Review of Meteorology and Medical Climatology.

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ANN ARBOR, MICH., U. S. A.:

METEOROLOGICAL JOURNAL COMPANY.

19, 21 and 23 Huron Street.

AGENTS: B. Westermann & Co., New York; 2 Thalstrasse, Leipzig; and 189 Boulevard St. Germain, Paris.

Single Copies, 30 cents. Per Annum, $3.00. In European Countries, $3 25.

Entered at the Ann Arbor Postoffice as Second Class Matter.

AMERICAN METEOROLOGICAL JOURNAL.

AN ILLUSTRATED MONTHLY

DEVOTED TO SCIENTIFIC METEOROLOGY AND ALLIED BRANCHES OF STUDY.

THE AMERICAN METEOROLOGICAL JOURNAL CO., Publishers and Proprietors,
Ann Arbor, Michigan.

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" IN COUNTRIES OF THE POSTAL UNION, - - 3.25 " "

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THE AMERICAN
METEOROLOGICAL JOURNAL

VOL. VIII. ANN ARBOR, MICH., JANUARY, 1892. NO 9.

ORIGINAL ARTICLES.

TERRESTRIAL MAGNETISM.*

BY PROFESSOR FRANK H. BIGELOW.

It is a pleasure to meet with such a paper as this, together with its two companions, "On the Unsymmetrical Distribution of Terrestrial Magnetism," and "On the Influence of Temperature upon the Magnetization of Iron and Other Magnetic Substances." It is like finding a spring of water in a dry and barren land, which may and will probably become a living well; in this case, too, the fountain seems to have a head with strong pressure behind it. For a half-century the science of Terrestrial Magnetism has been laboring under the burden of knowing no theory or working hypothesis that held out the least promise of correllating the heterogeneous mass of facts observed in all parts of the world, a statement that could hardly be made of any other important branch of science. Many volumes of observations upon the magnetic force and the movements of the magnetic needle have been produced, and yet with a feeling of discouragement, for lack of a plan upon which to arrange them. Were it not for the obvious advantages to navigation, the needs in connection with geodetic surveys, the suspicion that meteorology might have something to do with it, and the irresistible

* On the Causes of the Phenomena of Terrestrial Magnetism, and on some Electromechanism for exhibiting the secular changes in its horizontal and vertical components. By Henry Wilde, F. R. S., 1891.

scientific instinct that every force in nature must be accounted for, the depression would have been overwhelming.

Since the days of Gauss how little has been accomplished, and even his work has not proved so very fruitful. Gauss produced some fine analytical expressions, and an invaluable method of absolute measurements; but his Harmonic Analysis, with which his theory is so largely associated, has in reality given us little advancement in knowledge, for it is recognized that this Harmonic Analysis is only a method of intricate interpolation, a means of passing from point to point in an asymetric distribution, yet it conveys no notion, whatever, regarding the causes in which such a distribution originates. Furthermore, the very mathematical complexity of this device has rendered the science unusually forbidding, and has, in effect, tended to hinder its simple development. From the day of Gauss till now the subject may be quickly summarized. It consists in a large accumulation of absolute and differential observations, albeit vitiated by the diversity of methods in observing, discussing and publishing the results, the British Colonial observations under Sabine and the International Polar Commission observations of 1882–1883 being the most conspicuous products; in a considerable improvement in the instrumental means, especially in the direction of compensated instruments for the automatic elimination of the temperature corrections; in a large increase of resources drawn from the discovery of new mathematical relations in the general subject of electricity and magnetism. There is, however, a large literature that it is to be hoped will soon drop out of sight as inadequate, consisting for the most part, in a wordy comparison of theory with some one of the deflecting components, Horizontal Force, Declination, and Vertical Force. It is really incredible that any attempt should ever have been made to build up a theory from the action of any one of these magnetic elements, and yet the current literature is full of just such efforts. It was foredoomed to failure. Hence it may be seen that the analytical impulse given by Gauss, and the discussion of single components, are the chief causes why this subject has so long been languishing.

As a remedy for this state of affairs, it was evident that the variations of the needle must be discussed as caused by total deflecting forces, built up out of the observed components, ΔH, ΔD, ΔV, acting in space, which has led to the promising

conception of the subject, that the earth is a magnetic polarized conductor lying in certain cosmical uniform fields of force, emanating for the most part from the sun; and also we are happy to say that this paper by Mr. Wilde seems to have opened up a long vista of possibilities regarding the so-called permanent magnetism of the earth, which we hope will finally introduce us to the acting physical causes. The former idea has then to deal with the sources of magnetism external to the earth, and the latter with the larger part, which at the present time exists within the surface of the earth. Having prefaced the main topic of this paper with so long an introduction, we will proceed to a description of Mr. Wilde's idea and the model that expresses it, rather than to any criticism of the same.

Mr. Wilde wishes to account for the permanent magnetism within the earth, its sources, its present distribution, and the secular changes of this distribution throughout centuries of time—the old problem, to be sure—and, to his credit be it said, he has made up an electro-mechanism which not only produces the asymetric distributions existing at the present time, but apparently grinds out all such distributions as have been observed since the days of Columbus, that is, by turning a crank reproduces all the detailed features of the magnetic distribution which have, so far, bid defiance to scientific analysis. He has taken a common terrestrial globe, sixteen inches in diameter, cut it into hemispheres, wound each with insulated copper wire from the pole to the equator, the free ends being joined within the hemishell. Then at an angular distance of 23° 30′, the obliquity of the ecliptic angle, from these poles, he cemented on spherical caps terminating in spindle axles, these having suitable contrivances for carrying an electric current to the coils, while the globe rotated on these eccentric axles. Next, he used another terrestrial globe, eighteen inches in diameter, and on the inside of this fitted a couple of hemispherical iron wire gauze nets concentric with the shell, insulated also by more wire coiled upon it, the axles of this sphere being hollow so as to receive the axle of the first sphere, both sets of axles terminating in differential gears, which caused the inner sphere to lose one-thirtieth of a revolution (12°) for each complete revolution of the exterior sphere. What he intended to reproduce, as respects the earth, was a sphere revolving as if its axis were parallel to the geograph-

ical axis of the rotation of the earth, and inside it a sphere which was so placed that its axis was once parallel to the poles of the ecliptic; now, however, the whole inner system differentially rotating about the axis of the outer shell. He suggests that originally, while the earth was hot, all its material rotated about an axis perpendicular to the ecliptic; that upon cooling the time came when the moon was detached and the shell skewed about by 23° in the cataclysm, into its present position, the interior part continuing to rotate in the plane of the ecliptic. Thus, in his suggested view, the outer crust is comparatively thin and rotates about an axis, next comes a liquid or friction shell, if you please, and finally, the interior vaprous sphere, rotating at an angle of 23° 30′ from the outer, and also bodily carried about this outer axis at a certain rate. He regards this inner sphere as electro-dynamic, as the sun and all hot celestial bodies seem to have been from their beginnings; also that the shell is electro-magnetic, or as we say, permanently magnetized. The resulting system is intermediate between these two, and corresponds with the observed magnetic system of the earth, as if it were symmetrically distributed, which would be the case if the crust were a homogeneous conductor. Mr. Wilde has an arrangement for holding his observation needles in any selected zenith, as London, and by adjusting his resistances so as to produce the proper relative strengths in the two fields, gets the observed magnetic system of the earth complete, poles, equator and meridians in the right place, with the proper declination and inclination of the needles at a given station.

To cut the matter short I will go on to his next device. In order to reproduce the asymetric distribution of the magnetic meridians, the sea-areas were covered with magnetized sheets of iron, and the result was that all the known asymetric distortions of these meridians reappeared on his model even to the minutest details. There were the American and the European-Asiatic agonic lines, the North American small and the Siberian large areas of small declination of the needle, the minimum horizontal intensity at the poles in latitude 72°, the known east and west excursions of the declination in due order, the horizontal intensities greater in the Siberian than in the American areas, the inclination changing suitably from the magnetic equator towards either pole, having also its two points of maximum and minimum on this equator, the vertical intensity less

in the Siberian than in the American areas, and many other agreements even to the following the contours of the lines as regards the continents and seas.

All this is while the globes hold the same relative position to each other. Now, however, when the crank is turned so as to make the inner globe retreat at the rate of *22′.5 of arc annually*, he finds this complex system of lines and intensities to reproduce all the known facts as far back as the year 1492. I have the testimony of Mr. C. A. Schott of the United States Coast and Geodetic Survey, saying that he has much data of which Mr. Wilde is not cognizant, and that he has not been able to trip him up, or rather his machine, in any important particular, and that in fact the machine is much better than certain current literature on the subject. Take, as example, this wonderful statement regarding the observations of Columbus, which have heretofore tended to discredit his accuracy or his knowledge, p. 29. "The most ancient, as well as the most interesting observation of the declination in the North Atlantic, is that made by Columbus on the 13th of September, 1492, when he observed the needle to pass from the E. to W. of the meridian in latitude 28° N. and longitude 28° W. Since, however, the position assigned for the zero by Columbus has been considered only a rough approximation, an experiment was made to ascertain how far the results obtained on the magnetarium would agree with this early observation.

"Taking the zero of the declination at London in 1657 as a basis of calculation, there is a difference of 165 years between the observations for the epoch 1492–1657. Now 22′.5 × 165 years = 61° 52′ E. for the position of the zero line of the internal electro-dynamic sphere in relation to the British meridian on the mapped globe. When the globes in this position were brought under the compass needle, in latitude 28° N. and longitude 28° W., the declination was zero in the year 1492."

"But this is not the only point of agreement between the results obtained on the magnetarium and the observations on the variation made during the ever-memorable voyage of Columbus across the Atlantic; as besides the agreement in the westerly direction of the variation, there is a second zero on the magnetarium on the same parallel of 28° N., longitude 49° W., for the same epoch, which forms a closed curve within the parallel of 38° N. Now, it is on record that as Columbus advanced westward from the Island of Ferro, he was amazed to find the

third day after his observation of the variation, and when about 300 leagues west of Ferro, that the needle again pointed to the pole star. (Historie del S. D. Fernando Colombo.—In Venetia, 1571, Chap. 17). Although the difference of longitude between the zeros of declination in these early observations is less than that shown on the magnetarium, yet the same westerly direction of the variation, and the two zeros in mid-ocean on the same parallels of latitude, clearly identify the zeros of Columbus with those obtained on the magnetarium for the same epoch."

Our author proceeds with a wealth of illustrations of agreement extending over such vast regions of the earth and such long ranges of time, descending to minute details usually, as to preclude the possibility that there is anything wrong with his general analysis. He concludes that the period of a complete rotation of the fields relatively to one another is 960 years, and not 645 years, as magnetic tradition has it, the 960 year period also agreeing with Sir W. Thomson's value as given in a recent volume of reprints. The sea-areas are more highly magnetic, by reason (1) of the permanent low temperatures at the bottom of the ocean, which is favorable to high magnetism, and because shielded from the fluctuations of temperature caused by the heating and cooling of the land in diurnal and annual periods; and (2) by the fact that the ocean beds are thicker than the land-areas, and therefore contain more of the ferruginous iron ore. The secular variations of the magnetic meridians show that they pass quite smoothly over wide ocean or over wide land areas, but that they appear to hang along the coasts, where the break or faulting seems to produce greater polarity along the north and south lines. The American north magnetic pole is, as it were, held or retarded in its recessional march westward by the permanent magnetism stored up and retained by the cold and uniform conditions of temperature prevailing in that region. It will finally break loose and hasten to take up its place along with the more freely moving lines.

Mr. Wilde has also conducted some experiments upon the magnetic tractive power of metals under variations of temperature, and finds that the *mass* of the metal has much to do with the final result. If the mass is small, that is if the magnetization is practically reduced to a surface phenomenon, the disappearance of magnetism is almost complete at high temperatures,

but that when the mass is large and thoroughly magnetized to the core, consuming much time in the presence of a magnetizing force, it is much more tenaceous of its magnetism in the presence of heat—"the apparent increase in the magnetic power of heated iron is dependent upon the mass in relation to the magnetizing force." Applied to such large masses as the sun and the earth, some prevailing notions regarding the magnetic properties of these and other heated celestial bodies may be modified.

On one point our author feels able to use strong language, as follows: "From the various movements of the declination and inclination needles, correlated with each other in time, direction and amount, on different parts of the earth's surface, the theory of a fluid interior may now be considered to be as firmly established as the doctrine of the diurnal rotation of the earth on its axis," p. 31. This reads in marked contrast to the words of Sir W. Thomson in the *Treatise on Nat. Phil.*, Part II., p. 480 and p. 485, which says, "The earth, although once all melted, or melted all round its surface, did, in all probability, really become a solid at its melting temperature all through, or all through the outer layer, which had been melted; and not until the solidification was thus complete, or nearly so, did the surface begin to cool;" and, "regarding the present conditions of the earth's interior, it is not, as commonly supposed, all liquid within a thin solid crust of from 30 to 100 miles thick, but it is on the whole more rigid, certainly, than a continuous solid globe of glass of the same diameter, and probably than one of steel."

I have introduced these quotations to show that magnetism is to become profoundly interesting to other branches of science, and that it may contain in itself the key to many unsolved laws. The signs are ripening which indicate that it is among the most sensitive and the most pervasive of the cosmical forces. Inasmuch as it is in reality founded upon the same Newtonian law as the force of gravitation, we may expect it to go hand in hand with that fruitful aspect of the law, in unfolding the secrets of nature. If this is so, then also the indications will not be misleading, that terrestrial magnetism is rapidly emerging from that helpless condition in which it has so long been hindered from fulfilling its true mission in the service of science.

WASHINGTON, D. C., Dec. 23, 1891.

THE VERIFICATION OF WEATHER FORECASTS.

By Professor H. A. Hazen.

In considering or discussing the question of the verification of weather forecasts it is of the highest importance to settle definitely what a proper weather forecast is. It may be safely said that, since it is very difficult to foresee rain, every statement which contains a prediction of rain may be regarded as a proper weather forecast, though, as will be seen later, this is not strictly true in all cases. It will be admitted, probably, that the statement of a reasonable certainity is not a proper weather forecast. For example, on a winter day, with a high area extending over a large region, to say "there will be no tornado in twenty-four, forty-eight or even seventy-two hours," would not be a proper forecast. It would be like saying "the sun will rise to-morrow." This point has already been illustrated in the history of the Weather Bureau, for it was claimed at one time that certain predictions that there would be "no tornadoes" were verified ninety-seven per cent.

Another proposition is this, a "pure guess" is not a proper forecast; it would be like tossing up a penny and predicting that the head would come up. I think it can be shown that, after eliminating predictions in which rain is announced, more than three-fourths of the ordinarily so-called weather forecasts come under one of these two heads.

Again, a proper weather forecast must be dependent upon the average condition which is known to follow upon the appearances on any map, or, in other words, an abnormal condition cannot be predicted. It would seem that this is self evident, for the very essence of a forecast is a looking ahead, and if an abnormal condition occurs, or one that would not follow on an average of all the maps in existence, it is very plain that one could not predict it though having a perfect knowledge of all the maps.

A proper forecast, then, demands that one forsee approximately, just what changes in the position of a high or low area, in the appearance of the clouds, the direction of the wind, etc., will supervene, and that he be able to write out with his fore-

cast what he anticipates these changes will be, and if such changes do not occur, it would be evident, if the result predicted came to pass, that it did so not because of the knowledge which one had, but in spite of his lack of knowledge. For example, if one looks at a map and predicts a clearing sky from that and the appearance of a bright streak along the western horizon, while another looking at the same map and the same streak declares that there is not a sign of clearing and shows why it cannot in all probability clear, the final test should not be a clearing or clouded sky, but which view was correct as to the changes which would occur on the map. Of course it will be distinctly understood, that, in the large number of cases, or, as the saying is "in the long run," the one who forsees the changes best will make the best forecasts.

This may be put in still another form, if we had a thousand maps of the different days of a single month, the most successful forecaster would be the one who could make the highest average percentage, although on many of the maps he might not make more than seventy or seventy-five per cent., and this because of abnormal conditions not indicated on the average of all the maps. The best possible goal that one could set before himself would be to be able to make the same prediction from the same map over and over, although the result might be only seventy or seventy-five per cent.

A good illustration of the point here made, that the statement of a reasonable certainty is not a proper weather forecast which can be directly verified, is to be found in the predictions made for forty-eight hours. It is well known that the forecaster is at liberty to choose the map on which these long range forecasts are to be made and we may suppose that he would select only the maps on which he felt that there would be very little doubt as to the result. Now, during one year there were 533 of these predictions for forty-eight hours which gave ninety-one and seven-tenths per cent. verification, while during the same year the same person received for his predictions for twenty-four hours eighty-four and four-tenths per cent. A comparison of these figures would lead one to think that it was easier to make a high percentage for a long prediction than for a short one, but this would be a wrong inference. If properly judged the

predictions for forty-eight hours would be statements of reasonable certainties and would not come under the strict idea of weather forecasts for verification. Of course it will be distinctly understood that I do not intend to imply that these long range predictions are not more valuable than the short range ones, but I would like to show that either they should not be verified by the ordinary rules for short range predictions or that the two cannot in any way be compared and much less can they be compared from month to month or when made by different men.

If we had a rather complete set of rules applying to weather changes and a carrying out of these rules would enable us to enter a given formula with certain quantities upon our maps, we might make a solution of the formula which would give a fairly good idea of the forecaster's knowledge of the rules and formula. Such a method has never been attained and it is safe to say it never will be. This would practically consider only one side of the problem and would neglect what is in many respects, the more important side. It is true that what has occurred to the westward in the previous twelve or twenty-four hours is a partial guide to changes in any locality, but the conditions to the eastward, the changes that are likely to occur, the entrance of modifications from the eastward and such as are not indicated to the westward of a locality, would completely overthrow any result which might be obtained by employing in our formula only the conditions immediately at any region and to the westward.

I would say then, that to make a proper verification of a weather forecast, and one that shall be rigidly applicable to every case and enable us to compare those of different months or by different men, it should be done by an expert or one thoroughly acquainted with the average conditions and he should verify from the map on which the prediction was based and not from subsequent maps. If the verification is from a subsequent map then care should be taken to consider what abnormal conditions have occurred which could not have been anticipated. A rigid verification should throw out from the predictions all certainties and guesses as already suggested.

It seems to me that from what has preceded it is very plain that months having less rain have also a greater number of certainties and hence no fair comparison whatever can be made between the percentages of the different months. If the object

in the verification is to show the relative knowledge of different forecasters then most of the difficulties vanish, if the several men make predictions from the same map. If it is the desire to learn whether forecasts are deteriorating or improving, it can never be done by comparing percentages of all the forecasts. The following plan, I think, might be tried if it is demanded that a test be made. Let the maps of some previous month, say four years before, be gone over and forecasts be made a second time by the same person who made the forecasts in the first place, then if it be found that, judged by the same rules in the two cases, there has been a higher percentage in the second, it might reasonably be concluded that there has been an advance. It seems to me that this would be a most admirable and interesting experiment, and I believe the difference in the two results would be surprisingly small.

There is a source of difference in the present percentages which is often lost sight of, especially in comparing results of different years, and that is the change which has taken place in the limit for stationary temperature. It is easy to see that if the limit is five degrees all the year through there would be a great advantage in the summer as compared with the winter, for, in the latter case, the changes in twenty-four hours are very much greater than in the former. Since the limit was changed from five degrees to three degrees in the summer and then changed again to four degrees, it is very plain that no comparison whatever can be instituted between the forecasts of different years. The same is true in the case of the changes in the colder months. At present there is an abrupt change from four degrees in October to six degrees in November, and from six degrees in February to four degrees in March, while it is well known that the number of six degree changes in November is almost the same as in April, and in February as in March. It would be very much better if the limits were four degrees in summer, June to September, six degrees in winter, December to March, and five degrees in the remaining months.

There is still another consideration that should enter the verification. It is well known that the effort of the mind in making a long-range prediction is somewhat different from that for one of short range, so that if one should dismiss entirely from his thought everything but the stated prediction for twenty-four hours he would be in much better trim to make good forecasts. On the other hand, if one cannot confine him-

self to one thing, but is continually trying to determine where he can make a long-range prediction, his mind is thrown off slightly, and the result will be a slightly less satisfactory short-range prediction, so that in a rigid verification the number of long-range predictions should enter as a factor. Finally, it is suggested that the time occupied in making the forecast should enter as a factor in the final figuring up of the percentage of verification.

December 17, 1891.

THE MOUNTAIN METEOROLOGICAL STATIONS OF THE UNITED STATES.

By A. Lawrence Rotch.

At the present time there are in the United States but two summit meteorological stations in operation throughout the year, viz.: The Lick Observatory on Mount Hamilton, California, and the Blue Hill Observatory, in Massachusetts. The other stations about to be described have either been entirely abandoned or latterly have been maintained during part of the year only.*

I shall first describe those situated in the Eastern United States and shall commence with the oldest summit station in the world, that on Mount Washington, the highest of the White Mountains in New Hampshire, which has an altitude of 6,280 feet above the sea.

The establishment of a meteorological station was due to Prof. J. H. Huntington, who in 1870, when connected with the New Hampshire Geological Survey, formed a party to spend the winter at the summit for scientific purposes, as he had previously done on Mount Kearsarge. He was joined by S. A. Nelson, and the Chief Signal Officer detailed Sergeant Theodore Smith to accompany them. The expedition went up the mountain in November, 1870, and occupied a room in the old railroad station until May, 1871. Since that time observations have been maintained by the Government Signal Service, for which a special building was erected in 1874 southwest of the summit. It is a small one-and-a-half story wooden building, secured by heavy timbers bolted over the roof. Direct observations of the prin-

*Certain stations of the Weather Bureau situated upon high plateaux are excluded from consideration, for reasons given in a former article on Mountain Meteorology.

cipal meteorological elements were for many years made five times a day and three of these observations were telegraphed to Washington. In the autumn of 1887 the station was closed, and during the three following years it was opened only during the summer months, but last year it remained unoccupied throughout the year.

At no other observing station in the world has such severe weather been experienced as here, since the highest wind velocity often occurs with the lowest temperature, unlike the calms which accompany the cold at low levels. Thus, on December 16, 1876, the mean temperature for the day was -22° and the wind increased from 80 miles an hour in the morning to 180 miles an hour at midnight. Another great storm occurred in February, 1876, when the temperature fell to -50° and a wind velocity of 184 miles an hour was recorded. To appreciate these wind velocities it may be stated that at sea level, 40 miles per hour is a severe gale. Making allowance for the overregistering of the anemometer and the reduced density of the air at this elevation, a recorded velocity of 180 miles per hour is equivalent to a pressure of about 70 pounds per square foot, while a man cannot stand upright against a pressure of more than 20 pounds. The average hourly velocity recorded for the month of January, 1885, several days of which the writer passed on the summit of Mount Washington, was nearly 50 miles an hour, a rate which has probably never been exceeded elsewhere. No entirely satisfactory explanation of these extraordinary velocities has been offered, but it seems probable that the air flowing over the top of the mountain like water over a dam has its velocity accelerated in the same way, and this theory is supported by the fog which rises on the windward side and descends on the leeward side of the mountain. Added to this effect is the situation of Mount Washington in the track of cyclones coming from the west, whereby the barometric gradients are generally steep.

Another peculiar feature is the frost-work which forms to an enormous extent upon the windward side of every object when the weather is foggy and the temperature is below freezing. These frost-feathers are neither ice nor snow, they are elastic, and when broken show a granular fracture like marble or alabaster. As the frost formation increases in proportion as more fog passes the object, there is the greatest deposition towards the top of a pole, etc., where it may reach a length of four or five feet. The plain little signal station under these conditions

assumes the appearance of a frosted cake. Figure 1 illustrates this and shows the exposure of the thermometers in a screen outside a north window, while Figure 2 represents the anemometer, on the opposite end of the building and the observers sheltered by the porch. In foggy weather the frost-work forms upon the anemometer cups in such quantity as to bring them to a standstill or break them off the arms. This is the great obstacle to the measurement of wind velocity on Mount Washington and to

FIGURE I.—MOUNT WASHINGTON STATION IN WINTER.

obviate it, so far as possible, the cup wheel is changed every two hours in foggy weather. The amount of snow which remains on top in winter is very variable, there being sometimes none and again almost enough to bury the buildings.

For nine months in the year the two Signal Officers and their cook were the only residents at the summit and once or twice a month one of them went to the base for the mail, walking on or near the railway. These trips were often attended with danger,

and paralysis seemed to result from the close confinement at other times. In 1872 the assistant observer died and the observer-sergeant was two days alone with the dead body, as no one could come up on account of the hurricane and cold. Since that time it has been customary to have three men at the station. Telegraphic communication from the top of the mountain was maintained in winter by a cable laid on the track.

FIGURE 2.—OBSERVERS ON MOUNT WASHINGTON.

The scientific results furnished by Mount Washington have been disproportionate to the efforts expended to maintain the station during the seventeen years of its existence. This is largely due to the fact that the observations have not been pub-

lished in detail, permitting them to be discussed by meteorologists and also because a low-level station, to furnish normal data for comparison, was lacking. An exception must be made in the case of some simultaneous observations at the base and summit, carried out in 1872 and 1873, which were published and formed the subject of an interesting discussion by Dr. Hellmann, of Berlin. Later observations have been studied by Professors Davis and Hazen, and certain experimental work upon wind and rainfall has been performed under the direction of the Signal Service, but as an aid to weather prediction it can be said that the Mount Washington station has been of little use, since no systematic studies have been made of the relation of the conditions prevailing on the summit to those at a low-level station or to the general cyclonic and anti-cyclonic movements upon which our weather predictions are founded.

A second order meteorological station in the hotel on the summit of Green Mountain, Mount Desert Island, Maine (altitude 1,541 feet), was maintained by the Signal Service during the summers of 1889 and 1890. This situation is excellent and my own observatory, on Blue Hill, thus lost the distinction of being the highest station on or near the Atlantic coast.

A long step downwards and southwards brings us to the lowest of all the stations to be described, the Blue Hill Observatory, ten miles south of Boston, which has an elevation of 640 feet above the sea and nearly that above the valley. The principal summit on which stands the observatory, exceeds in height the others of the range by more than one hundred feet and so has the nature of an isolated hill, commanding an unbroken view of the sea-level horizon 33 miles distant, the New Hampshire Mountains, 70 miles away, and 120 towns and villages. The situation is thus admirable for a first-class meteorological observatory, which was opened by the writer in 1885. The design of a building for purely meteorological purposes was difficult, as there were no observatories in this country which could be taken as models. A view of the observatory as finally completed is shown in Figure 3.

As a result of an examination of the foreign observataries many self-recording instruments were obtained, so that for several years all the chief meteorological elements, atmospheric pressure, air temperature, humidity, wind, sunshine, cloudiness and precipitation have been automatically recorded. From these records, controlled by direct observations, the hourly

values for five years have been reduced and printed, through the generous co-operation of the Harvard College Observatory, in the *Annals* of that institution. As a part of the regular work for five years, daily weather predictions for the Associated Press were made by Mr. Clayton from the data of the government synoptic weather maps and from the local observations. I may say that it was, no doubt, owing to the successful example of this observatory that the Weather Bureau was induced to allow its observers to make local weather forecasts for their districts, a proceeding which has given good satisfaction.

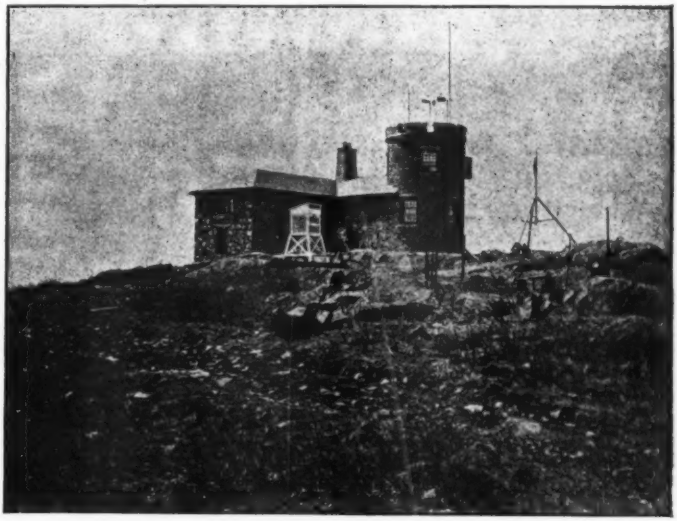

FIGURE 3.—BLUE HILL METEOROLOGICAL OBSERVATORY.

Besides the routine work, various investigations have been carried on. For several years hourly observations of the amount, kind and relative velocity of the clouds, have been conducted by Mr. Clayton with a view to benefit weather predictions by connecting the clouds with the cyclonic phenomena. In order to convert the relative cloud velocities into absolute measures it is necessary to know the heights of the clouds and during the last two years many cloud altitudes have been determined by means of the trigonometrical method which was employed at

Upsala, Sweden. Although Blue Hill is not generally considered to be a mountain, yet many meteorological phenomena differ from those at a lower level and in order to find out in what way the observations of temperature, rainfall, etc., differ from those below, two low-level stations, provided with self-recording instruments, are maintained at the base of Blue Hill and in the valley, while the records of the government station in Boston have also been employed in a discussion of the periodic and non-periodic variation. It should be said that the greater part of this work has been done by Messrs. Clayton and Fergusson and that to the latter gentleman the observatory is indebted for many ingenious mechanical devices.

FIGURE 4.—SUMMIT OF PIKE'S PEAK.

Upon the summit of Mount Mitchell, North Carolina, the highest peak of the Appalachian range, (6,700 feet,) a series of observations was conducted during the summer of 1873 by the Signal Service, in connection with simultaneous observations at the base of the mountain. Since that time nothing has been done with this admirable site for meteorological purposes.

We now pass across the continent to Pike's Peak, Colorado, where for fifteen years the Signal Service maintained, at an altitude of 14,134 feet, the highest meteorological station in the world. This mountain rises abruptly about 8,000 feet above

Colorado Springs, which is within ten miles of the summit. The open plain extending to the eastward offered unusual advantages for noting such cloud and storm phenomena as originate or move to the eastward of the mountain, and even the peaks to the westward are enough lower not to obscure the storm and cloud conditions below the level of the observer on Pike's Peak. The substantial stone Signal Station upon the summit, which is shown in Figure 4 and a nearer view in Figure 5, was built in 1873, and for several years five daily observations were made and three telegraphic weather reports were sent daily to Washington, except when the line was broken. In 1882, on account of the cost and difficulty of maintaining the telegraphic reports,

FIGURE 5.—PIKE'S PEAK STATION IN SUMMER.

they were abandoned and in the autumn of 1888 the station was closed. This was the more to be regretted because Professor Loud had equipped an observatory at Colorado Springs which was to serve as a base station to that on Pike's Peak.

Professor Pickering, the director of the Harvard College Observatory, has done meteorology a great service by publishing the detailed observations made during the fifteen years on Pike's Peak. From these data the average annual temperature is 19°, the extremes having been 64° and –39°, which, together with the average daily changes, are much less than the corresponding temperatures on Mount Washington. Notwithstanding

the fact that Pike's Peak is more than twice as high as Mount Washington the wind velocity is much less, and the days are comparatively infrequent when the mean hourly velocity exceeds fifty miles. The period of wind velocity is nearly the reverse of that of temperature, that is to say the highest average monthly velocity occurs with the lowest mean monthly temperature, and *vice versa*. The same is true of the diurnal period, the maximum velocity occurring at night and the minimum velocity in the day, which is the reverse of that at low-level stations, where the greatest velocity occurs in the afternoon and the least at night. It is unfortunate that this station should not have been provided with a recording barometer and thermometer from which the seasonal and diurnal periods of atmospheric pressure and air temperature could have been studied.

Pike's Peak is celebrated for its electrical storms which occur when the air is moist, and generally when a light, soft snow is falling. Sparks then emanate from the fingers of the outstretched hands and the rotating anemometer cups look like a circle of fire. Only once, however, has the station been struck by lightning. Some important experimental work has been done by the government here, such as the measure of the diminuition of temperature with altitude, the determination of dew-point formulæ, etc. Observations of the total solar eclipse of 1878 were also made on Pike's Peak.

Mount Hamilton, in California, on which is the famous Lick Observatory, is a wooded mountain 4,300 feet above the Pacific Ocean, which is in plain view from the summit. Although the observatory is primarily astronomical, meteorological observations are carried on, and there are self-recording instruments for meteorological elements as well as for seismic disturbances.

With a view to determining the climatic conditions necessary for astronomical work, the Harvard College Observatory, by the aid of the Boyden fund, maintained for a limited time several elevated stations, provided generally with simple self-recording instruments, which were controlled by direct observatories. Such were the stations on the summit of Mount Lincoln (14,200 feet), and at 13,250 feet altitude, on the side of its neighboring peak, Mount Bross, in Colorado, and on Wilson's Peak (6,000 feet), in Southern California.

Any statement of the results of meteorological observations on mountains would be incomplete without a reference to the expedition of Professor Langley, in August, 1881, to Mount

Whitney, in California, the highest peak of the Sierra Nevada range. Two stations were maintained, one at Lone Pine, at a height of 3,800 feet, and the other at Mountain Camp, at an elevation of about 11,600 feet, and observations were made daily here and sometimes at the crest of the mountain, 14,500 feet.

The discussion of these observations, which perhaps belong more to physics than to meteorology, served to change our theory of the nature of heat received from the sun. By means of an instrument called a "bolometer," it was shown, contrary to the accepted theory, that the greatest atmospheric absorption occurs at the blue end of the spectrum and that the obstacles to the transmission of light-waves through the air diminish as their wave length increases, and their refrangibility consequently diminishes. A yellow tinge is thus imparted to the solar rays by the imperfectly transparent medium through which we see them and, since the sun possesses an atmosphere of its own, exercising a selective absorption of the same character, it follows that if both these dusky-red veils were withdrawn the photosphere would show a very distinct blue, and as the blueness of the sun is a measure of its incandescence, the sun is much hotter than has been supposed. But the determination of the amount of heat received by the sun, the source of all our atmospheric movements, is of more importance to meteorology. Professor Langley's researches raised the solar constant to three calories, which means that, independent of radiation and the absorption by our atmosphere, the vertical solar rays would heat three grammes of water 1° C. per minute over each square centimeter of the earth's surface exposed to them.* If the earth were stripped of its atmosphere, Professor Langley has calculated that its temperature would be –200° c., so that mercury would remain frozen under the tropical rays of a sun, undiminished by atmospheric absorption, because of the enormous amount of heat radiated into space. Even with our atmosphere, were it not for the selective absorption by which the sun's rays are transformed into obscure heat and so cannot pass out, the earth would be uninhabitable. The observations indicated that it is the aqueous vapor which controls this selective absorption.

Interesting series of hypsometric, thermometric and hygrometric observations were conducted by Professor Langley, but they are overshadowed by the importance of the preceding.

* Previous determination of the solar constant had been 2.3 by Crova and 2.5 by Violle.

DURATION AND INTENSITY OF RAINFALL AT ROCHESTER, N. Y., AND VICINITY.*

By E. Kuichling, C. E.

In the foregoing an attempt has been made to deduce a rational estimate of that proportion of surface, on a given urban drainage area, from which substantially the whole of the rainfall will run off into the sewers during the progress of a heavy storm; and it now remains to ascertain the probable maximum intensity or rate of fall, of the rain in the locality, in order to guard against engorgements of such sewers. For this purpose the exact duration and depth of water, of both the entire storm and its variable showers, must be known, as it frequently happens that during a rainfall which lasts one or more hours without intermission, the intensity of the precipitation will change greatly from time to time, thus causing the entire storm to resemble a series of hard showers connected together by intervals of mere drizzle. The average intensity of such a storm is of comparatively little consequence in dealing with the important problem of maximum flow in sewers, since it may be only one-third or one-fourth the rate of fall which has occurred during some one of the component hard showers, and which would probably govern an engineer in fixing the dimensions of a sewer. Hence, when the records of a certain rainfall do not show that the rate of precipitation has been practically uniform throughout the entire specified duration, the results obtained by gaugings of the corresponding sewer-discharge will be utterly misleading, and their indiscriminate use may give rise to errors of design which may entail serious consequences.

The usual rainfall records merely give the total depth of water precipitated during certain regular intervals, such as twenty-four, twelve or six hours; another very limited class of records indicate the approximate duration of the showers and the depth, the time in such cases being occasionally estimated when the attention of the observer at the beginning or end of the rain has been diverted by other matters; while a third class of records, which are, however, rarely kept outside of the most important meteorological stations, give the rates of fall at all times during the entire continuance of the rain. For sewer-discharge computations, the first of these three classes is almost

* From Report on the Proposed Trunk Sewer for the east side of the city of Rochester

entirely worthless, and their collection may accordingly be considered as a sheer waste of time; the second has much value, but must be used cautiously, especially when the rainfall happens to be of longer duration than about thirty minutes; the third class is by far the most valuable, and should be kept in every growing city where sewerage works exist. The best method of securing such data is from a number of self-recording rain-gauges located in different parts of the municipal area, since a heavy shower may pass over a city in such manner as to deliver great quantities of water in one section, while another portion may receive only a light sprinkling. Cases of this kind have frequently been observed in this city, particularly during the past year, when opportunity for comparison was afforded by the records of the two gauges maintained by the writer, and those of the United States signal service and the city water works department, the four similar instruments being located at a distance of about one mile apart. It is greatly regretted that none of these gauges were of the self-recording type; but the observations which were used as a basis for computing the dimensions of the trunk sewer were all carefully checked by several other parties with respect to duration, so that their general accuracy may safely be accepted. The great expense connected with the purchase and maintenance of automatic gauges precluded the writer from availing himself of such instruments, and, as a consequence, it was found too late that only a few of the many records thus obtained could be used with reasonable certainty.

To illustrate the importance of these statements, the case of the rainfall of June 28, 1888, in this city may be cited. Between 5:30 A. M. and 7 A. M. a continuous moderate rain had given a depth of about 0.32 inches, and in the four succeeding hours, between 7 and 11 A. M., when the rain ended, one inch of water fell, thus giving a total of 1.32 inches in five and a half hours, and hence an average rate of 0.24 inches per hour. But the rain was noticed to fall quite heavily at certain times during the said four hours, the record giving three distinct sharp showers, of about fifteen, twenty and ten minutes' duration, respectively, and mentioning an estimate that the intensity during these showers was about three times as great as that of the intermediate light rains. Now, since one inch fell in four hours, and assuming the rate during the said forty-five minutes to have been three times greater than during the remaining

three and a quarter hours, as stated, the actual rate during the said aggregate period of forty-five minutes would be 0.55 inches, while that which obtained during the balance of the time was 0.182 inches per hour; hence the maximum rate was here more than double the average for the entire storm. The maximum rate was, however, larger than the estimate named, inasmuch as the corresponding maximum flood-flow in the outlet sewer of a district of 133.0 acres, and of which an aggregate of 35 per cent. may fairly be considered fully impervious, was then found to be 37.52 cubic feet per second, of which probably about 1.22 cubic feet was sewage proper, while the remainder was storm-water from the roofs and streets, together with a certain amount of infiltration through the joints and masonry of the system of sewers. This latter element is not very large, and would be estimated liberally if taken at 1.0 cubic foot per second, so that the volume of rainfall flowing off at the period of maximum discharge can be placed at 35.3 cubic feet per second. But this should represent the quantity of water which falls per second on the total amount of impervious surface in the district; and assuming the latter at 46.5 acres, or thirty-five per cent. of said 133.0 acres, we find that a rainfall at the rate of 0.55 inch per hour will give only 25.6 cubic feet per second, or only seventy-two per cent. of the observed discharge; hence the conclusion that either the area is more impervious than estimated, or that the intensity of the rainfall during a period not exceeding twenty-five minutes was somewhat greater than 0.55 inches per hour, even if ample allowance be made for the remnants of the previously existing storm-flow due to the light rain at the assumed rate of 0.182 inch per hour.

The foregoing citation will doubtless suffice to point out the necessity of securing the rainfall data needed in the consideration of the discharge from surfaces, by means of automatic and self-registering devices, instead of trusting to the judgment of even the most careful and well-trained observers. Many other similar instances could be selected from the mass of material thus obtained in the course of the past year; and wherever such experiments are repeated, it is now urgently advised to make use of a large number of automatic rain-gauges, scattered about on the various separate drainage basins and located not more than about 1,500 feet apart, if only a single season be allowed for the collection of statistics. Most of the showers, moreover, occur during the night time, and with the usual appliances the

records for such cannot be secured unless two sets of observers are employed. Measures should also be taken to cause every Signal Service station in the cities of our country to be equipped with the best automatic gauges, and to have the results thus obtained carefully tabulated, in order that communities may be spared the great outlay of soon reconstructing sewers whose dimensions were based upon the deceptive records of rainfall as heretofore kept.

TABLE L.

Date.	Amount, inches.	Time.		Average rate of fall per hour, inches.	Maximum rate of fall per hour at any time, inches.
		Hours.	Minutes.		
July 3, 1871	1.13	0	30	2.26	2.26
July 18, 1871	0.83	0	20	2.49	2.49
September 25, 1872	1.50	1	00	1.50	8.00
August 18, 1875	1.20	1	00	1.20	2.40
August 29, 1875	1.30	1	00	1.30	1.30
October 23, 1875	1.40	1	00	1.40	2.50
June 22, 1877	1.08	1	00	1.08	2.00
July 28, 1877	1.20	1	00	1.20	3.00
July 29, 1877	1.42	0	26	3.24	3.24
October 4, 1877	1.49	1	00	1.49	6.00
July 2, 1884	1.12	1	00	1.12	3.00
November 24, 1884	1.00	1	00	1.00	2.00
July 26, 1885	0.96	0	06	9.60	9.60
October 29, 1885	1.20	1	00	1.20	2.40
July 24, 1886	1.10	1	00	1.10	3.00
July 26, 1886	1.80	1	00	1.80	6.00

That the subject is already beginning to receive some recognition, is shown by the recent publication of the data derived from the self-registering rain-gauge at Washington, D. C., in response to a request from the superintendent of sewers of that city; and as the information thus elicited serves to indicate the striking differences in the rate of intensity of the rainfall during the progress of a heavy storm, the following quotations from the circular of the Chief Signal Officer, issued about one year ago, may be of interest: "The observations (referring only to Washington) cover a period of seventeen years, from January, 1871, to December, 1887, in which time rain or melted snow has been recorded 1,543 times. The rainfalls exceeding one inch in depth number 192, of which thirty-seven yielded two inches and upwards in depth for the entire duration of the storm. Pre-

cipitation exceeding two inches occurred four times in August, and six times each in June, July, September and October, while they were rare in other months, and never happened in February. The heaviest fall from a single storm was 5.80 inches in nineteen hours on July 29 and 30, 1878. Of equal and perhaps greater importance than the amount recorded during a single storm is the rate which falls in any single hour. Assuming that a less rate than one inch per hour is not especially important, examination was confined to those cases in which the rate was greater. Sixteen such cases have occurred as shown in the foregoing table.

"Thus it appears that on two occasions 1.50 inches fell in one hour, and on one occasion 1.80 inches fell in the same time; but it will be seen that in all these three cases, the maximum rate was far in excess of the average rate, the table showing that for short periods of time the rain then fell at rates of eight inches and six inches per hour. The greatest rate recorded, however, was the extraordinary one of 9.60 inches per hour, which fell on July 26, 1885, but lasted only six minutes."

It may be remarked that for the purpose of determining the percentage of rainfall-discharge from urban surfaces, the maximum rates of precipitation for values less than one inch are also of much importance, as the difference in such percentages for various rates of fall may thereby be ascertained. The exact duration of the maximum rates, moreover, should likewise be carefully tabulated, since in small districts, the surface drainage may perhaps be fully concentrated before the heaviest portion of the shower has ended, in which event the corresponding rate must be used in computing the said percentage. Concerning the latter it is reasonable to suppose that the same should vary in some degree both with the intensity of the rainfall and its duration, in all cases where this time is equal to or exceeds the period required for the drainage from the most distant points of the area to reach the point of observation in the sewer. Thus the percentage of discharge from a given district due to a uniform rate of 1.0 inch should be somewhat greater than that derived from a similar rate of 0.5 inch in the same length of time, and it should also increase with the duration of the rain when falling uniformly. So far as can be learned, no successful attempt has yet been made to compute these differences in rates of discharge, which are of so much importance in works of municipal sewerage or drainage, and it is a source of much

regret to the writer that the lack of the said data prevented an examination of this nature in connection with his work during the past year.

In a paper on the maximum rates of rainfall by Desmond Fitz Gerald, C. E., of the Boston water works, printed in *Engineering News* of May 31, 1884, the author refers to some of the heaviest rainfalls which occurred in the vicinity of Boston for a series of years. The most noteworthy of these is the storm of August 16, 17, 18 and 19, 1879, which yielded a total depth of 6.23 inches, and of this amount 3.43 inches fell in ten and a half hours on the 18th, the maximum being at the rate of about 1.0 inch per hour. The greatest intensity of rainfall observed was recorded July 20, 1880, when 0.75 inch fell in thirteen minutes and 1.17 inches in thirty minutes, thus giving rates of 3.46 and 2.34 inches per hour respectively. Maximum intensities ranging from 1.5 to 2.0 inches per hour, and lasting from eight to forty-five minutes, seem to be usual attendants upon nearly all the storms whose diagrams are exhibited; and as such durations will generally admit of the concentration of the drainage from small urban districts, the importance of providing for such falls will at once be recognized.

While the imperfect rain records for Rochester and the surrounding territory do not indicate that intensities of more than 1.5 inches per hour are of frequent occurrence, yet it is barely possible that greater rates would be discovered if self-registering gauges were used. It may therefore be of interest to note a few more of the heavy rains which have been observed at other places. At St. Louis, the following were recorded in 1884: 5.05 inches in one and a quarter hours, 5.22 inches in three hours, 6.17 inches in five hours, and 7.55 inches in twenty-nine hours; at Providence, R. I., 4.49 inches fell in one hour on August 6, 1878, of which amount 3.50 inches came in thirty-six minutes, thus giving a rate of 5.85 inches per hour; and on August 13, 1888, a storm occurred which gave 3.10 inches in eight hours, the maximum intensity being 3.75 inches per hour; at Leland, Miss., a rainfall of 11.5 inches occurred on August 15, 1888, and was followed on the next day by one of nine inches; at Waltham, Mass., 5.63 inches in three hours was recorded on August 21, 1860; during a heavy storm over eastern Connecticut in August, 1874, a depth of twelve inches of water fell in forty-eight hours, and five inches in four hours; another great storm in Connecticut, and which extended over the New England States

generally occurred on October 3 and 4, 1869, when the following depths were recorded at different localities within about thirty hours: 8.43 inches at Hartford, 8.44 inches at Colebrook, 9.37 inches at Middletown, and 12.35 inches at Canton, the greatest rate then recorded being four inches in two hours. The continuous rain in New England on February 10 to 14, 1886, however, surpassed most of the previous ones in both intensity and duration, as well as disastrous consequences. From the accounts of this storm given by Professor W. Upton, in Volume VII of *Science*, and by the commission of engineers consisting of James B. Francis, Eliot C. Clark and Clemens Herschel, in their report to the city of Boston on the prevention of floods in the valley of Stony Brook, it seems that the greatest fall occurred on the 12th, when 6.66 inches fell in twenty-four hours at New London and a total of 8.93 inches in fifty-eight and one-half hours; the same storm also yielded the following depths at other cities; 3.41 inches in forty-nine and one-half hours, with 2.99 inches in twenty-four hours at New York; 8.13 inches in seventy and one-half hours, with 5.65 in twenty-four hours at Providence; 5.62 inches in fifty-five hours, with 4.45 in twenty-four hours at Boston, and 4.78 inches in seventy-seven hours, with 3.30 in twenty-four hours at Newburyport.

With regard to the extent of territory that may be covered by a heavy shower at any instant of time, observations show exceedingly wide variations. The storm area in our latitude is commonly several hundred miles in diameter, and occasionally exceeds two thousand miles in diameter, but the rain area is usually very much less, especially in the case of sharp thunderstorms where sometimes only a few square miles of the earth's surface is covered by the rain-cloud. The writer has frequently noticed both the passage and the approach of such discharging clouds, and estimates that for a precipitation lasting about fifteen minutes, the least area covered by the densest portion of the rain, as viewed from a distance, is about four miles in length and one and one-half miles in width, thus giving an area of about six square miles. For shorter durations, the area may be correspondingly smaller; but in general, the clouds which furnish rain-falls that greatly concern the capacity of sewers, are considerably larger in extent than any single drainage area within ordinary municipal limits. On the other hand, to point out how great an area may be covered by a single storm, the following data given by James B. Francis, C. E., and Professor

W. Upton, may be cited. For the storm of October 3 and 4, 1869, the area on which eight inches or more fell, had a length of sixty-five miles, with an average width of twenty-eight miles; the area on which nine inches or more fell was about fifty miles long by twenty-one miles wide; the area on which ten inches or more fell was about thirty-four miles long by fifteen miles wide; and the area on which eleven inches or more fell, had a length of about twenty miles with an average width of nine miles; similarly for the storm of February 10 to 14, 1886, the area on which over eight inches of water fell was 750 square miles; that on which from six to seven inches fell, was 1,500 square miles; and that on which from four inches to five inches fell, was 2,750 square miles. These areas were computed by platting the observed depths of rainfall at different places on the same day upon a map, and then drawing the contours showing the lines of equal depth; from the map thus prepared, the required areas may then be easily determined.

Numerous other instances of severe rainfall might be cited, but the foregoing will doubtless suffice to exhibit not only the exceedingly variable character of the rate and duration of heavy storms, but also the necessity of carefully studying the data afforded by each particular locality. As already stated, to secure a reliable estimate of the amount and rate of precipitation in this city, simultaneously with gaugings of the maximum flood-discharge of the principal outlet sewers in the eastern portion of the city, two ordinary rain-gauges of special design and carefully rated, were procured and maintained for the past year by the writer, and placed in charge of thoroughly competent observers. One of these instruments was located at the Municipal Gas Company's works on Canal street, where it was under the care of Edward C. Delaney, Esq., the superintendent of said works; while the other was located at the Rochester Bridge Works on Leighton avenue, where it was in charge of Alfred M. Mosscrop, C. E. Between these two points on the east and west sides respectively, the United States signal service station is located, while the rain-gauge maintained by the Water department of the city is situated about one and one-quarter miles to the south. Four observations of the same rain at as many different points thus afforded the means of comparison with respect to intensity and quantity, while a careful timing and general observation of the rainfall, as viewed from the writer's office, secured many checks upon the records of those in charge of the

gauges, and furnished clues to some of the numerous anomalies of discharge which were subsequently found. To obtain the depth, the water collected by three of these gauges was carefully weighed on delicate balances, and from this weight the corresponding volume was derived; hence, as the area of the nine-inch opening presented to the rain was accurately known, the resulting depth was easily found. At the Signal Service station, on the other hand, the depth is obtained by direct measurement with a graduated rod in a vessel considerably narrower than the gauge-orifice. In this manner of gauging, the rate at all times during the progress of a storm cannot be secured, and with only one set of observers, many showers which happen during the night time must necessarily be passed without specific record. The data thus derived can accordingly not be regarded as giving a perfectly correct view of the rainfall, but it is the only one which is here available.

In order to ascertain the frequency and intensity of heavy showers in this portion of the State, the writer was kindly supplied by the Chief Signal Officer with the statistics relating to rainfalls of more than 0.25 inch per hour collected at the stations in Rochester, Buffalo and Oswego, from 1870 to 1888 inclusive; by the authorities of Cornell University with similar statistics relating to Ithaca from 1879 to 1888 inclusive; and by the chief engineer of the Rochester Water Works, with the records kept at Mt. Hope reservoir and Hemlock lake from 1878 to 1888 inclusive. All of this information has been arranged by months in the appended Tables Nos. 11, 12, 13, 14 and 15, and is submitted in lieu of something better. To exhibit the essential facts in more convenient form, however, they have been summarized in the following Table M, which gives the recorded number of rains of different intensities during the cold and warm seasons, together with the deduced average number of times per year that a rain of the specified intensity has been observed at the several localities mentioned.

It should be remarked that the figures relating to the number of rains given in the above table are not worthy of much credit, owing to the absence of self-registering devices. For example, three of the six rains at Rochester, with rates of from two inches to three inches per hour occurred in 1888, and were all obtained from the gauges maintained by the writer; hence, instead of such a rain—which caused serious overflows in nearly every sewer wherein observations were taken—occurring

only once in three years, as per table, it has in fact occurred three times in one year, and twice on the same day! Furthermore, it is the writer's firm conviction that at least two rains of similar intensity occurred in 1887 in said city, no record of which is contained in said table; and he has an equally strong conviction that if proper automatic gauges had been in use at the two stations in said city, the list of heavy showers would have been enormously increased during the course of the past eighteen years. Doubtless the same might be said of the other stations named, and hence the necessity for the use of better apparatus in obtaining these important statistics. Wherever much reliance has been placed upon such data as exhibited in Table M, sewer engorgements and cellar floodings have, curiously enough, soon followed in the wake of the sewerage system, and large outlays are demanded for the construction of relief conduits when direct storm-overflows cannot be provided. The rainfall problem, therefore, requires the most careful consideration in connection with the proportioning of sewers or drains in urban districts, and it is singular that so comparatively little work in this direction appears to have been done in the past twenty years.

The important question is with reference to the duration of the heavy rainfalls, which cause the capacity of the sewers to be exceeded, and thus give rise to damage in the adjacent cellars. An attempt to solve this problem for the locality of Rochester with the data afforded by Tables Nos. 11, 12, 13, 14, and 15, was made in the following manner; and while the said data are doubtless deficient, yet they constitute the only available means of reaching any reasonable conclusion in the premises. The intensities of all these rainfalls, or the rates of precipitation in inches per hour, were first computed from the given total depth and time, and were then platted as ordinates with the corresponding actual durations of the rain as abscissas; a multitude of points on the diagram was thus obtained, each one representing by its location a different rate of fall for definite periods of time; and since the rains of relatively light intensity were far more numerous than the heavy ones, these points were much closer together in the lower portion of the diagram than in the upper part. Now by connecting the successive highest points by straight lines, an irregular envelope, or line enclosing all of the remaining points, will be obtained, and the ordinates of such envelope will represent the probable

maximum intensities of the rainfall in this locality for the corresponding abscissas, or periods of time.

TABLE M.

Rate of Rainfall, Inches per hour.	Number. From Nov 1 to April 1.	Number. From April 1 to Nov. 1	Total Number.	Number of years observation	Locality.	Average Number per year.
0.20 to 0.50	12	71	83	18	Rochester	4.61
0.50 to 0.75	2*	24	26	18	"	1.44
0.75 to 1.00	0	9	9	18	"	0.50
1.00 to 1.25	0	6	6	18	"	0.33
1.25 to 1.50	0	4	4	18	"	0.22
1.50 to 1.75	0	2	2	18	"	0.11
1.75 to 2.00	0	1	1	18	"	0.05
2.00 to 3.00	1†	5	6	18	"	0.33
0.20 to 0.50	0	42	42	15	Hemlock Lake.....	2.80
0.50 to 0.75	0	9	9	15	" "	0.60
0.75 to 1.00	0	6	6	15	" "	0.40
1.00 to 1.25	0	2	2	15	" "	0.13
1.25 to 1.50	0	2	2	15	" "	0.13
1.50 to 1.75	0	1	1	15	" "	0.07
1.75 to 2.00	0	1	1	15	" "	0.07
2.00 to 3.00	0	1	1	15	" "	0.07
0.20 to 0.50	1	46	47	17	Buffalo	2.76
0.50 to 0.75	0	16	16	17	"	0.94
0.75 to 1.00	0	2	2	17	"	0.12
1.00 to 1.25	0	4	4	17	"	0.24
1.25 to 1.50	0	1	1	17	"	0.06
1.50 to 1.75	0	1	1	17	"	0.06
1.75 to 2.00	0	0	0	17	"	0.00
2.00 to 3.00	0	3	3	17	"	0.18
0.20 to 0.50	0	17	17	17	Oswego.....	1.00
0.50 to 0.75	0	9	9	17	"	0 53
0.75 to 1.00	1‡	0	1	17	"	0.06
1.00 to 1.25	0	2	2	17	"	0.12
1.25 to 1.50	0	2	2	17	"	0.12
1.50 to 1.75	0	1	1	17	"	0.06
1.75 to 3.00	0	0	0	17	"	0.00
0.20 to 0.50	1	21	22	9	Ithaca	2.44
0.50 to 0.75	0	15	15	9	"	1.66
0.75 to 1.00	0	3	3	9	"	0.33
1.00 to 1.25	0	2	2	9	"	0.22
1.25 to 3.00	0	0	0	9	"	0.00

A closer examination of the diagram, however, shows that by omitting only a very few of the highest points, the said envelope may conveniently be represented by two straight lines,

* March, 1881, and November, 1885, lasting 1 hour 20 minutes and 15 minutes respectively.

† March, 1880, lasting only 5 minutes.

‡ November, 1876, lasting 20 minutes.

which form an abrupt angle with each other at a point corresponding to an intensity of about 0.87 inch, and a duration of about 1.0 hour. The line to the left of the point of intersection is quite sharply inclined, while that to the right is more nearly horizontal, thus showing very clearly that the maximum uniform intensity of the rainfall diminishes rapidly as its duration increases from a few minutes to one hour, and that for rains of uniform intensity lasting more than one hour, the rate of diminution is comparatively slow.

To express the relations of the probable maximum intensity of the local rainfall to its duration in mathematical terms, let (t) denote the duration in minutes, and (y) denote the maximum intensity in inches per hour; for periods less than one hour we will then have:

$$1) \ldots\ldots\ldots\ldots y = 3.73 - 0.0506\, t,$$

while for periods longer than one hour and less than five hours, we have:

$$2) \ldots\ldots\ldots\ldots y = 0.99 - 0.002\, t.$$

There is, however, more or less doubt about the accuracy of the data in the said tables, and it may be argued with much force that, under the circumstances, it would be preferable to consider averages rather than extremes; also, that for application in Rochester, the data relating to that city alone should be taken into account, especially since the same appear to be more numerous and in much greater detail than the others. Proceeding on this assumption, and grouping together such of the 20 rainfalls of greatest intensity (ranging from 0.86 inches to 3.17 inches per hour) as have equal durations, we find that the averages for periods less than one hour will be much less than the values obtained from equation (1) above; and that the values derived from the following substitute for said equation will agree quite closely with such averages for periods ranging from fifteen minutes to one hour:

$$3) \ldots\ldots\ldots\ldots y = 2.10 - 0.0205\, t.$$

The results of the computations of (y) from equations 1) and 3) for different times (t), as well as the aforesaid averages of the observed intensities, are arranged in the subjoined table.

Inasmuch as the durations which are to be considered in planning outlet sewers for large districts are rarely less than fifteen minutes, and are usually much in excess of that limit, it has appeared to the writer that in view of all the uncertainties

attending the case, it would be more justifiable to base his computations for the size of the East Side trunk sewer upon the probable maximum rates of rainfall derived from equation 3, instead of using those obtained from equation 1. The results thus found are generally much larger than those given by the empirical formulas in common use, which predicate a rainfall of not more than one inch per hour for drainage areas of all magnitudes.

TABLE N.

Duration of rain in minutes (t).	Computed intensity (y) from Equation 1.	Computed intensity (y) from Equation 3.	Average of observed intensities. Table No. 11.	Number of such observations.
5	3.48	2.00	3.00	1
8	3.33	1.94	2.88	1
14	3.02	1.81	3.17	1
15	2.97	1.79	1.73	4
20	2.72	1.69	1.95	2
25	2.46	1.59	1.70	2
30	2.21	1.49	1.43	2
35	1.96	1.38	1.32	1
40	1.70	1.28	1.40	2
45	1.45	1.18	1.39	1
50	1.20	1.07		0
55	0.95	0.97	0.95	1
60	—	0.87	0.86	1

The foregoing method of ascertaining the probable maximum intensity of the rainfall of any particular locality, was subsequently found to be practically identical with that adopted by Prof. F. E. Nipher, of St. Louis, in the consideration of the rainfall of that city, a brief account of which is contained in Vol. IX of *The American Engineer*, Chicago, 1885. On platting the records of the heaviest rains observed at St. Louis during a period of 47 years in the same manner as described above, the envelope enclosing all the points was found to be an equilateral hyperbola, whose equation Prof. Nipher considers to be: $yt = 6$, the duration (t) being taken here in hours instead of minutes. This formula represents the statement that 6 inches of rain may fall in one hour, or that it may be spread over a greater number of hours; so that if the heaviest rain lasted uniformly for two hours, the maximum rate would then be $y = 3$ inches per hour, and 1.50 inches per hour for 4 hours, etc.

An examination of the rainfall diagram for Rochester indicates that the envelope might possibly be an hyperbola, but not an equilateral one.

In conclusion, it may be repeated that no great accuracy is claimed for the above-mentioned equation 3, which is of the most importance in the computation of the dimensions for large sewers, nor for the data upon which said equation is based; it is merely an effort to utilize the only available records of the local rainfall in a rational manner, and to remove the subject of urban sewerage somewhat further from the realm of vague conjecture.

CORRESPONDENCE.

MOUNTAIN METEOROLOGY.

To the Editors:—In your recently published article on "Mountain Meteorology," I may, with your kind permission, call attention to an apparent incongruity, and shall be much pleased if you will explain it away.

On page 154 it reads: "It has been shown by Dr. Hann that the Föhn owes its extreme warmth, as well as its dryness, to the descent from the ridges on the north side of the Alps, and that it does not bring it from further south. The warmth of the Föhn is explained by the fact that a mass of air sinking into one of higher pressure is warmed at the rate of 1° for each 300 feet of descent, and a rapidly sinking stream of air which is so rapidly heated must be relatively very dry." And again, a few lines above: "The cool night wind is caused by the sinking of the cold air into the bottom lands and it is most intense in narrow valleys where there is a great difference between the temperature of the valley and the plain."

To an ordinary reader it would appear from this that the mere descent of a mass of air is in one instance accused of causing it to become intensely warm and in another to become intensely cold, and this contrast stands out even more clearly, when it is said on page 151: "Slowly descending currents of cold air fill the valleys like rivers, while the summits receive the air warmed dynamically by descending from greater height."

No doubt, you are yourself well aware of this discrepancy, but the remedy you seem to imply, that it should make a differ-

ence whether the descent takes place slowly or rapidly, is contrary to the mechanical theory of heat.

As a contribution towards the solution of this problem I may mention that I gather from your article (1) that under average or normal conditions the temperature of the atmosphere decreases uniformly at the rate of 1° F. for 300 feet of rise, (2) that a mass of air gets heated at this same rate during descent and (3) that it gets cooled at this same rate during ascent. It follows herefrom that under normal conditions a rising or sinking mass of air will wherever it moves meet with air of the same temperature as its own, and (4) for air to come to the earth's surface abnormally hot or cold it must have been as much abnormally hot or cold at the elevation from which it started. And therefore, when the Föhn sometimes causes a sudden rise in temperature of 60° F. above the normal, it must have had a temperature 60° F. above the normal when it started to descend from the ridges on the north side of the Alps, and it therefore remains for Dr. Hann to explain how this air gained this abnormally high temperature in its elevated position, unless it derived it from standing over the heated sand of the desert of Sahara. The sand dust it carries with it seems, however, abundant proof of the origin of these hot winds.

The cool night winds from the mountains find a ready explanation according to the same figures. The air must have been abnormally cooled before it descended into the valleys. During clear nights the surface air gets cooled by radiation, and as it thereby becomes contracted it will seek the lowest level, and particularly flow from the mountain slopes into the adjoining valleys. As, however, the radiation is more intense on the mountains than on the lower land, it follows that the air accumulating in the valleys must be colder than that of the plains. The higher temperature on the mountains is not caused by the air being dynamically heated by descending from a greater height, but simply by the cooled surface air immediately flowing off the slope of the mountains, thereby making room for the adjacent air which has not as yet been cooled by radiation.

An explanation of the phenomenon of hot winds might possibly be suggested, when you further say: "Loomis showed that in case of a storm passing over the Rocky Mountains, the vapor contained in the air would mostly fall on the west side, so that the air would descend on the east side deprived of its moisture

and with a temperature above that which prevailed in the Salt Lake basin, on account of the latent heat liberated by the condensation of the vapor." If we, however, figure for ourselves the stratum of air, called a cloud, in which condensation takes place, it is in the first place evident that before condensation sets in the layer of air is in equilibrium vertically, or, has a specific gravity just according to its level, and secondly, during the process of condensation or rain, this body of air not only looses the weight of the rain falling from it, but expands to a larger volume, on account of the latent heat liberated, wherefor its specific gravity becomes much less than that of the sursounding air. It must, therefore, necessarily rise above the level of the clouds, and I am unable to conceive how this same air can immediately afterwards appear as surface-air in the Salt Lake basin, according to Loomis.

FRANZ A. VELSCHOW.

BROOKLYN, N. Y., November 28, 1891.

[EDITORIAL NOTE.—The normal decrease of temperature with elevation is, as stated in the article referred to (page 150 of the current volume), about 1° F. for each 316 feet of elevation, or in metric measures 0.57° C. per 100 meters. Ascending masses of air cool at the rate of 1° F. for 183 feet, or 1° per 100 meters (so long as there is no condensation), and descending currents are warmed in the same ratio. In explaining the warmth of the Föhn, on page 155, the 1° for each 300 feet quoted was 1° C., or 1.8° F., giving the rate of 1° F. for 183 feet above stated. The warmth of the Föhn produced by the rapid descent of the air as contrasted with the cool night wind, cited on page 154, which slowly descends into the valleys, is due to the dynamic heating of the former being in excess of the cooling of the latter by radiation.—A. L. R.]

CURRENT NOTES.

ERRATA IN "NEW HIGH LEVEL STATIONS IN FRANCE" IN THE NOVEMBER JOURNAL.—In first line of article, p. 316, for five *read* fine; on p. 325, line 18 from bottom, for Infeldt *read* Imfeld.

THE CLIMATE OF TROPICAL AFRICA.—At the Cardiff meeting of the British Association attention was drawn to the importance of knowledge of the climate of Tropical Africa, and a committee was appointed to collect information upon the subject and to render it generally accessible. The work consists of two branches: (1) the collecting and epitomizing such records as have been made; (2) endeavoring to secure the establishment of a network of stations throughout that vast region; not merely the British portion, but right across the continent, because, happily, scientific men of different nations rarely fail to be good

friends and to co-operate in work which is for the benefit of all. The committee request information of all trustworthy and regular meteorological observations made in Tropical Africa, and the loan of any unpublished *data* of that nature. Instructions for observing and blank forms for the entry of observations will be supplied to all residents in that portion of Africa who will undertake to observe regularly and to return to us their forms duly filled up. All communications should be sent to G. J. Symons, Secretary, at 62 Camden Square, N. W. London.

PATHS OF BAROMETRIC MINIMA ACROSS EUROPE.—The European meteorologists have always paid more attention to the usual paths of barometric minima across their continent than we have to ours. Whether this is due to the greater regularity of the paths there or to the attention of our meteorologists having been drawn in some other way, it is not easy to say. Perhaps it is due to both causes. In the October (1891) number of the *Meteorologische Zeitung*, Dr. Van Bebber, the forecaster for the German coast and marine service at Bremen, goes anew over the subject of regular paths of "lows" over Central and Western Europe and gives the results graphically for each month of the year. The paths are quite numerous, and they anastomose extensively, but there are five principal ones. The most important of all is the path which runs northeastward at sea from west of Ireland to the northern point of Norway. This is the most frequently traveled in autumn and winter, and is the path for many of the storms that come from America. Many storms leave it to pass northward into the Polar Seas.

The one next in interest is Dr. Van Bebber's No. V, which is the most southern, entering the continent near the Pyrenees and crossing Italy and Rumania. It strikes a curve, convex southward. It is strongest in May and October, but traces of it can be seen during the rest of the year. Between I and V lie the three others with their branches. Their general course is northeast.

PRIZE ESSAY ON EQUATORIAL AFRICA.—The King of the Belgians has offered a prize of 25,000 francs ($5,000), to be awarded in 1897, for the work giving the most satisfactory replies to the following questions:

Describe, from the sanitary point of view, the meteorological, hydrological, and geological conditions of the territories of Equatorial Africa. Deduce from the present state of our knowledge concerning these matters the hygienic principles suitable for these regions, and lay down, with observations in support of the conclusions arrived at, the best scheme of life, diet, and work, as well as the system of clothing and form of dwelling best adapted for the preservation of health and vigor. Describe the symptomatology, etiology, and pathology of the diseases which characterize the regions of Equatorial Africa, and indicate the treatment, both prophylactic and therapeutic. Define the principles to be followed in the choice and use of medicaments and in the establishment of hospitals and sanatoria. In their scientific researches, as well as in their practical conclusions, competitors should particularly take into account the conditions of existence of Europeans in the different parts of the Congo basin. The prize is open to foreigners as well as to Belgian subjects. Competitors must send in their works to the Minister of the Interior and of Public Instruction at Brussels before January 1, 1897.—*Scottish Geographical Magazine*, November, 1891.

VARIATIONS IN THE FREQUENCY OF LIGHTNING-STROKES AND HAILSTORMS.—The records of the insurance companies give valuable data for the study of destructive lightning-strokes and hailstorms. These records have been utilized, especially in Germany, by von Bezold, Lang, Bühler and others, and M. Lancaster sums up the results in an interesting way in a recent number of *Ciel et Terre*. It appears that the frequency of lightning-strokes has been gradually increasing since 1821. This cannot be due to the deforesting, because the latter has not been progressive, nor to the increasing use of iron in buildings, nor to telegraph and telephone wires, nor to the increasing smoke in manufacturing and other operations, because all of these would cause greater frequency in towns, while the strokes are actually more frequent in the country, in the ratio of nearly two to one.

The lightning-strokes also show a definite variation in frequency in a period of eleven years, with a minimum at the time of maximum frequency of sunspots.

The latter fluctuation is also found in the frequency of destructive hailstorms, but in this case there is no sign of the

progressive increase in number found in the other. The minimum of frequency also falls in this case with the maximum of sunspots. M. Lancaster mentions a grand period of sunspot frequency, fifty-six years in length, and suggests that the lightning-stroke frequency shows apparently a sensitiveness to this, while that of hailstorms does not, and suggests that the latter is more independent of extra-terrestrial causes.

PHENOLOGY.—In his work on the results of European phenological observations of plants * Dr. Hoffmann gives several general conclusions which are well worth putting in English. They follow in a modified and condensed form.

(1) Since the mean temperature for a week or a month is only a fragment of the annual curve and the stage reached by vegetation is due to the temperatures which precede as well as that of the present month or week, an agreement between the two is not to be expected. This is all the more true because the temperatures are taken in the shade, while the plants grow in the sun.

(2) The spring flowers are retarded northward for evident reasons. The summer flowers are much less retarded because of the longer summer days in the north.

(3) For the same latitude and elevation above the sea, there is a retardation in the unfolding of leaves and in the spring flowers as one passes from West Europe eastward. This is due to the milder climate of the coast.

(4) On the other hand, the warmer continental summer causes the late flowers to appear earlier to the eastward.

(5) In the higher mountains the spring flowers are later (due to later disappearance of snow); the summer flowers are at about the same time as at lower elevations (due to stronger insolation); and the ripening of the fruit is retarded about in proportion to the absolute elevation (due to the earlier appearance of decline of temperature).

(6) The ripening of fruit is earlier eastward, later westward, due to the continental summer.

(7) The interval between flowering and the ripening of the fruit is shorter northward, at least in cases where they ripen at all, for it sometimes happens that a plant is common where it cannot ripen its fruit, as the vacciniums in North Siberia.

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* Resultate der wichtigsten pflanzen-phænologischen Beobachtungen in Europa. Professor Dr. H. Hoffmann, Giessen, 1885.

(8) The relation of the interval to the elevation above the sea is complicated, varying for the species and the exposure.

(9) The extensive Arctic phenological province is not reproduced on the mountains in Southern Europe. The compensation due to the longer summer days of high latitudes does not obtain on the mountains.

(10) The order of succession of different flowering species is the same throughout. This permits the selection of certain widely distributed, early flowering, normal plants to which the others can be referred—for instance the hazel, or wild currant, or wild plum.

Dr. Hoffmann also mentions some things in phenology which remain to be done and these gaps are in part filled by the work of two of his pupils which lie before us.* They are both theses for the doctor's degree at Giessen. The first relates to winter-rye, and it commends itself at once that important cereals should be selected for such studies. Adopting the name *isophane*, as used here to designate the lines of simultaneous appearance of the same phase of life as drawn on the map, Dr. Made's isophanes for flowering are on the whole nearly east and west and vary from twenty days before (the time for Giessen) in Central France and Northern Italy to forty days after in Lapland and Finland. The isophanes for fruiting are somewhat more irregular, but also extend from twenty days before to forty days after—the latter near the White Sea. The retardation of flowering is about four days for each degree northward but it increases rapidly in high latitudes. For harvesting the retardation is slightly less. The retardation of flowering for altitude averages eight or nine days for each hundred meters, becoming rapid at high elevations, while for harvesting it is an acceleration. The interval between flowering and harvest increases, on the whole, from about thirty-seven days in latitude 40°–45°, to fifty-one days in latitude 51°–55°. From here it decreases, but is somewhat irregular, to latitude 70°. The interval at different elevations increases from forty-five days at 200 metres to fifty-six days at 700 metres.

Dr. Voelcker studied the intervals of the horse-chestnut and the honeysuckle. The interval of the first was curiously con-

* Phænologische Beobachtungen ueber Bluehte, Ernte und Intervall von Winterroggen (*Secale cereale hybernum*). Philipp Made, Mainz, 1890, octavo, 87 pages, 3 maps.

Untersuchungen ueber das Intervall zwischen das Bluehte und Fruchtreife von *Æsculus Hippocastanum* und *Lonicera tartarica*. Karl Voelcker, Giessen, 1891, 43 pages, 2 maps.

stant for elevation, varying, and then only irregularly, from 129 days at sea-level to 135 days at 1,000 metres. For latitude it decreased northward from 165 days at latitude 41° to 117 days at latitude 60°. Some of the same was true for the honeysuckle. The interval was about fifty-five days with no constant change with altitude, while for latitude it ran from 121 days at 41° to fifty-one days at latitude 60°.

These pamphlets are good models for those who desire to work up American phenology.

THE UPPER STRATA OF THE ATMOSPHERE.—There is a very interesting article by Professor Förster in the *Verhandl. der Gesell. für Erdkunde zu Berlin*, B.l. xviii. No. 6, in which the question concerning the limits of the atmosphere and the circulation of its upper strata are clearly enunciated, and the observations most likely to contribute to their solution indicated. Calculations, based on observations of the refraction of light, led to the belief that, at the height of about fifty miles, the air became so rare that this distance might be taken as the height of the atmospheric envelope. During the present century, however, observations have been made of the distances of meteors from the earth when, owing to the heat engendered by their rapid flight through the atmosphere, they begin to emit light, and the results seem to indicate that the atmosphere extends upwards to about 110 miles. But then the question arises, whether the incandescence of these meteors is caused by the resistance of an atmosphere properly speaking terrestrial—that is, a mixture of oxygen and nitrogen moving with the earth—or takes place in an interstellar atmosphere. The fact that the Aurora Borealis extends to a height of 300 to 350 miles tells in favor of the latter hypothesis. We are all aware that the orbits of heavenly bodies, such as Encke's Comet, Jupiter's satellites, etc., are subject to changes only to be accounted for by the action of some resisting medium, and it would be very satisfactory if it could be proved, by spectrum analysis, for instance, that the Aurora occurs in a medium different from our atmosphere—gases ejected by the sun or produced by the explosion of meteoric bodies. Suppose, in the next place, that this atmosphere—not merely a medium for the propagation of light, which we call ether, but a gaseous substance capable of considerable resistance—does exist, and moves with the solar system and independently of the relative move-

ments of the earth; it will, then, naturally exercise a pressure on the outer strata of the terrestrial atmosphere. The height of the barometer will be increased by this pressure during the morning hours, the station of the instrument being then on the front side of the earth. There certainly is a morning maximum, but at present it is impossible to eliminate the effect of pressure from an external atmosphere from those due to temperature, attractions, etc. Luminous clouds are phenomena of the greatest importance in the investigation of the circulation of these upper strata. To these Herr O. Jesse has paid particular attention. They were first noticed in August, 1883, after the eruption of Krakatoa, and are no doubt formed by particles projected to a great height, where they receive the light of the sun all through the night when near the Pole. The clouds appear to wander periodically from one Pole to the other, being always found in either hemisphere during the summer, as though they sought the region of least pressure. Professor Förster's paper gives a glimpse of a very interesting field of observation, in which great assistance may be given by those even who are not provided with scientific instruments.—*Scot. Geog. Mag.*, Nov., 1891.

CLIMATE OF PARAGUAY.—The most of Paraguay lies north of the southern annual isotherm 70, and is thus in the torrid zone, although the southern boundary is fully 3°, or about 200 English miles, south of the tropic of Capricorn. In other words, Asuncion has a higher mean annual temperature than Lima, which is nearly 1,200 miles nearer the equator. Without pausing to explain this interesting but easily intelligible fact, it is here sufficient to state that a series of observations covering many years, made by Mr. Henry Mangels, German consul at Asuncion, who is approved by several authorities, shows the average annual temperature there to be 75.85° F. Mr. Child states, upon the authority of Mr. Mangels, that the thermometer varies during the summer months (there) of December, January and February, from a minimum of 55.4° or 57.2° to a maximum of 100.4° (C., 13°, 14°, and 38°); while in July, or mid-winter, it ranges from 41° at night to 86° in the daytime (5° and 30° C.).

The summer heat is not torrid, but is tempered by frequent storms. * * * September and October are generally rainy, but there is no fixed rainy season such as we find further north in the tropical zone. On the whole, the climate of Paraguay is

considered healthy, and during nine months out of the twelve it may be characterized as temperate.

Mr. Mangels gives the annual and average rainfall at Asuncion for nine years as follows:

Year.	Inches.	Year.	Inches.
1877	58.2	1883	45.1
1878	102.9	1885	52.6
1879	62.4	1886	50.2
1880	62.0		
1881	65.7	Average	61.8
1882	57.4		

In the seven years from 1877 to 1883 the average per year of rainy days was 79, of cloudy 72, and of clear 214. On an average there are ten frosts per year, and ice sometimes forms in the country. In June, 1888, the thermometer registered 36.9° F. at Asuncion. These records of temperature and precipitation compared with those of Key West, Fla., in a corresponding latitude, for the six years ending in 1859, show that at Asuncion the average precipitation was over 26 inches greater and the temperature 1.09° less.—*Report of Statistician (Dep't of Agr.), Nov., 1891.*

Some very interesting papers were read and discussions held at the meeting of the International Congress of Hygiene in London, during August, upon the influence of various meteorological conditions and soil as causative factors of disease. Among others may be mentioned a paper by Alfred Haviland, in which he attempted to show that there is a higher mortality from cancer in women who reside in low-lying valley areas, in which clay and limestone are the chief constituents of the soil. His conclusions were thought to be drawn from rather narrow premises. The influence of tropical climate upon the residents of temperate zones naturally elicited much interest, since so many of our European neighbors are of choice, or by necessity, subjecting themselves to practical tests in India and Africa. Dr. Felkin, of Edinburgh, in introducing the subject, stated that for safety a comparatively high altitude should be selected. He divided the tropics into three vertical zones, a hot, a temperate, and a cool or cold belt. The first has a mean annual temperature of 72°–82° F., and a range of elevation from sea-level to 300 feet. The second, a mean annual temperature from 41°–73° F., and included altitudes between 3,000 and 12,000 feet. This

could be conveniently subdivided into two on a basis of temperature, the lower including regions with a range from 55°–73°. The third division had a mean annual temperature of 30° to 41° F., and lay between the elevations of 12,000 and 16,000 feet. According to his investigation, it has been found that an altitude between 6,000 and 10,000 feet is best suited to English and North German residents in the tropics.

The views expressed in the discussion that followed by those who have had experience in such climates, were to the effect that the manner of life, the sanitary and food conditions, had even more influence in the adaptation of Europeans to the conditions existing in tropical climates than the meteorological factors. W. J. H.

THE CLIMATOLOGY OF BRAZIL.—A pamphlet by Sr. H. Morize, entitled *Esboço de uma Climatologia do Brazil*, has been issued from the observatory of Rio Janeiro. The author divides the country into three great zones—tropical, subtropical, and temperate. The first, in which the mean temperature exceeds 77° F., embraces the northern part of Brazil, and is bounded to the south by a line running along the south side of the state of Pernambuco, across Goyaz, and somewhat to the south of Cuyabá. The second lies between the isothermals of 77° and 68°, and extends into S. Paulo and Paraná, leaving a portion of these provinces, with Sta. Catharina and Rio Grande do Sul, to form the third zone, in which the mean temperature oscillates between 68° and 59°. The tropical zone may be again divided into three regions, the Upper Amazons, Matto Grosso and the interior of the states on the Atlantic border, and the Littoral. On the Upper Amazons there are two rainy seasons, the principal one lasting from the end of February to June, and the other from the middle of October to the beginning of January. During the intervening dry season the rivers fall sometimes as much as 46 feet. Sr. J. Pinkas found that the mean temperature was 79°, but the maximum was 103°, which is comparatively low. The heat, however, was very oppressive, owing to the excessive moisture in the air. The prevailing wind blows from the southwest, and is frequently interrupted by calms. Towards the end of the great rains the phenomenon known as *friagem* occurs, which is a sudden fall of temperature produced by an influx of cold air from the Andes. It can only take place on a calm day, and is preceded by a high temperature, an

almost complete saturation of the air, and a barometric fall of about two inches. In the second subdivision heavy rains occur in spring and summer, and the thermometer often rises as much as 35° in a few hours. These sudden changes are produced by the rapid alternations of northwest and southeast winds, the former warm and moist, the latter always very cold. Dr. Morsback gives the mean temperature as 79°.25 F. The average rainfall is 45.9 inches, and the number of raining days eighty-five. In this region also there is a period of *friagem*. The third subdivision is characterised by rains in summer and autumn, and particularly during the month of April. The differences of temperature are much less than in the other subdivisions, 84° F. having been recorded at Vizeu in Pará during December, the warmest month, and 80° F. at the same hour, 9 A. M., during July, the coolest month. The mean rainfall is about 58 inches. In the dry season the prairies are withered and scorched by the heat, and the cattle that feed on them suffer terribly. Occasionally the rains do not make their appearance at all, and then famine spreads throughout the country. This calamity has occurred six times already during the present century.

The subtropical zone closely resembles the warm regions of the south of Europe. Both the temperature and the rainfall vary considerably according to the situation. The climate of the third zone is one of the finest in the world, and therefore the states comprised in it have been almost exclusively chosen by European immigrants. The rainy season does not occur in the same months as in the other regions; rain falls chiefly in the winter and autumn. As the distance from the equator increases, the transition between the wet and dry seasons becomes less distinct. Sr. Morize's paper is very useful for those who wish to study the subject minutely, for he has collected numerous records of observations from all parts of the country.—*Scottish Geographical Magazine*, November, 1891.

BIBLIOGRAPHICAL NOTICES.

CEYLON METEOROLOGY.—The "Administration Report," by Major F. J. Day, for 1890, gives the observations for sixteen stations. There are also sixty-seven rainfall stations reporting monthly. The solar radiation temperature averages from fifty to sixty-five degrees higher than the maximum temperature in

the shade and these figures do not differ much in the individual months. The nocturnal radiation thermometer averages from two to eleven degrees below the minimum in the shade. The rainfall for the year reaches 148.88 inches for Ratnapura (an average for twenty-one years) and 96.68 inches at Nuwara Eliya (for about the same period). It was below the normal in 1890 for all sixteen principal stations—by 23.7 inches at the first and 27.9 inches at the two stations above mentioned. The number of days in which rain fell in 1890 was 229 for the first station and 189 for the second.

INDIAN MONTHLY WEATHER REVIEW.—This publication is much like our own, though somewhat different in shape. It began with the year 1891, the first number being issued at Calcutta, for January last. It is written in a more readable form than ours,—is not so concise—and contains from twenty-four to thirty-six pages. A very complete abstract of observations is given at the end, and there are five plates, giving eight charts of mean condition of the meteorological elements for the month in India and Burma. These are the 8 A. M. pressure and wind, the variation of the normal, mean pressure and wind, mean maximum and minimum temperatures and variation of the mean daily temperature from the normal, and the distribution of rainfall and its variation from the mean. With these come separate uncovered pamphlets called "Registers of Original Observations in 1891, reduced and corrected."

INDIAN METEOROLOGICAL MEMOIRS.*—The consecutive form in which these memoirs are published is excellent, because it permits them to be bound together in suitable volumes. The memoir on the June cyclone, 1887, in the Arabian Sea, is by Mr. F. Chambers and occupies 110 of the 134 pages, as well as all the twelve plates. The daily history of the storm is briefly given and is illustrated in the charts. The subject of abnormal winds before the existence of the cyclone is especially discussed. The distortion of the cyclone by the monsoon also

* Indian Meteorological Memoirs, being occasional discussions and compilations of meteorological data relating to India and the neighboring countries. Published by the government under the direction of J. Eliot, M. A., meteorological reporter to the Government of India: Vol. IV, Part VII; X—The Arabian Sea cyclone of the 4th to the 13th of June, 1887, with a demonstration of the practicability of foretelling storms by the method of abnormals two or three days sooner than by the ordinary method of actuals; XI.—On the meteorology and climatology of Northern Afghanistan. Calcutta, 1891. Quarto, pages 395 to 528, plates XLIV to LV.

receives especial attention. At a distance of 250 miles from the center, the winds on the west side are almost radially inflowing, while on the other sides they were nearly tangential; those on the north side were very weak, while on the south side they were very strong. The direction of motion of cyclones in the Arabian Sea in May and June is found to be about eight points (from six to ten) to the left of the direction of the normal monsoon wind.

The meteorology and climatology of Northern Afghanistan is discussed by Mr. W. L. Dallas, from three sets of travelling observations for two years—October, 1884, to October, 1886. There were very few halts of over a month's duration. The material is skillfully used and even the hourly mean temperatures for the months are computed.

CYCLONES OF THE ARABIAN SEA.*—This study relates only to cyclonic storms and the list gives fifty-four in the 242 years under review. Of these, however, seventeen occurred since 1870, giving a probable average of one such storm per year. They generally originate on the northern limit of the southwest monsoon and the place of origin undergoes an annual oscillation. Also, no cyclones are formed on the Arabian Sea when the limit in question is on the land. They are most frequent early in June and early in November. They generally start near the Maldive or Laccadive Islands and strike a parabolic path northwestward, terminating in a west branch before the monsoons, and in an east one after. Their motion is somewhat slow and irregular. The barometric fall is equal on all sides and is gradual except near the center. The initial stage is marked, not by calms, but by an abnormal northerly wind. The calm center is well marked with the other characters usually recorded for this phenomen. The rain is heavy on all sides, but most so toward the north. Occasional cyclones come from the mainland of India, but they affect but a narrow strip of sea, and during the northeast monsoon small cyclones descend on the Arabian Sea from the highlands of Persia and Baluchistan.

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* Cyclone Memoirs, Part IV. An inquiry into the nature and course of storms in the Arabian Sea and a catalogue and brief history of all recorded cyclones in that sea from 1648 to 1889, by W. L. Dallas, Esq., Assistant Meteorological Reporter of the Government of India. Published by the Meteorological Department to the Government of India under direction of J. Eliot, M. A., Meteorological Reporter to the Government of India. Calcutta, 1891. Octavo. 129 pages, 17 charts.